Simulation and Theoretical Investigation on Transparent Glass PV/T Water Collectors

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Abstract— **Now a days the applications of solar energy are increasing day by day. The challenge for any solar based researcher is to design a system with higher efficient performance than the existing system. In this paper too such challenge has been considered and new system has been designed as a mean to suggest better photo-voltaic thermal water collectors. The factors which plays a major role in the evolution of this project was cost of PV/T system and poor thermal performance of existing PV/T water system. In this work a new PV/T water system with transparent photovoltaic panel was being introduced in place of non-transparent cell panels. The purpose of this work is to overcome the drawbacks of PV/T water systems available in the market. The measure being taken produces better performances in terms of electrical as well as thermal performance. Experimental setup has been drafted using AUTOCAD software, fabricated and simulated using MATLAB SIMULINK software. The results expected are higher than existing PV/T system.**

Keywords **— PV/T Water, Transparent glass, AUTOCAD, Higher performance, MATLAB etc**

I.INTRODUCTION

Solar systems that convert solar energy to thermal energy and then using this thermal energy to generate electricity are usually large scale systems. The main aim of this work is to generate both electrical thermal powers simultaneously. In addition to that of that the concept of electrical analogy with mechanical stream leads to the effective origination of the project. Both small scale and large scale applications of photovoltaic technology can be observed today. An emerging technology, which combines the generation of dual power via single mean, is known as Photovoltaic/Thermal hybrid collectors, which are usually abbreviated as PV/T collectors.

This project investigates the performance and economics of Photovoltaic/Thermal hybrid collectors that convert solar energy to both thermal energy and electricity simultaneously. Usually a Photovoltaic/Thermal hybrid collector consists of two layers: A glazed or unglazed PV layer at the top and beneath it, an absorber layer, which absorbs heat from the PV layer. The absorber layer has an inlet and outlet for fluid circulation. But PV/T collector discussed in this project consists of heat tubes made of copper material and cells are being mounted on a transparent glass cover panel. The main advantage of this kind was equivalent generation of electrical and thermal power. For effective success of this work simultaneous contribution of power electronics and thermal contribution is required. [1] Now a day’s most of the renewable energy technologies produce DC power and hence power electronics and control equipment are required to convert the DC into AC power.

Designing of such thermo-mechanical system is not that much easy. In case designing of such system design loss factors are need to be considered. In case of these PV/T collectors such losses are being classified in to two types. They are electrical losses and mechanical losses. The main electrical losses are in the form of transmission, distribution and sometimes shadows falling on the solar cells (Heat conversion source).The main thermal losses are predominantly in the form of radiation heat transfer losses and minor conduction convection combo losses.

The main disadvantage associated with the existing PV/T collectors are drop in thermal efficiency during non-sunny days. The reason is those solar cells are mounted on the fiber sheet. Such a non transparent sheet retards the radiation of sunlight falling on the heat tubes mounted under it. Such problem was being identified and attempt was being made to reduce such loss in thermal efficiency. The concept of transparent PV cell module has been introduced and mounted on the top glaze of the water collector.In this work procedure to improve the performance of PV/T water collectors has been discussed with its simulation using Matlab software.

II.LITERATURE SURVEY

S.A.Kalogirou [8] considered a domestic flat and hot thermosyphonic system and a larger active system suitable for a block of flats or for small office buildings. The results show that a considerable amount of thermal and electrical energy is produced by the PV/T systems but there will be a drop in thermal efficiency during non sunny days and the performance as well as economic improvement methods is being suggested. Thus, the PVs have better chances of success especially when both electricity and hot water is required as in domestic.

Krismadinata [5] in his work describes a method of modeling and simulation photovoltaic (PV) module that implemented in Simulink/Matlab. He found that it is necessary to define a circuit-based simulation model for a PV cell in order to allow the interaction with a power converter. Characteristics of PV cells that are affected by irradiation and temperature are modeled by a circuit model. He simplified the steps and employs a PV equivalent circuit with a diode as model. The simulation results are compared with difference types of PV module datasheets. Its results indicated that the created simulation blocks in Simulink/Matlab are similar to actual PV modules, compatible to different types of PV module and user-friendly.With the help of such simulation analysis a clear view on modeling a PV module in Matlab simulink has been cleared and it forms the basis for elimination of unnecessary subsystems.

Arindam Chakra borty [1] in his work he determined that there is a need for new switching devices with higher temperature capability, higher switching speed, and higher current density/voltage capability. The growth in alternative energy markets will provide a stronger pull for further development of these technologies. In addition he found that as a mean to meet the needs of future power generation systems, power electronics technology will need to evolve on all levels, from devices to systems. There is a need for modular power converters with plug and-play controls.

M.Sridharan et.al [6] & [7] in his suggested methods to improve the performance of solar flat plate collector system by increasing the flow time of the fluid flowing through the collector. With the help of such concepts and also by making problems identified by S.A.Kalogirou [8] in this work he opted for a transparent PV module.

As a result of transparent PV module sunrays falling on transparent material (Glass=1) will pass through it and fall on the heating tubes carrying water at a mass flow rate of unit kg/min.

[2] C. V. Nayar in his work he classifies PV system analysis and made a deep and thorough analysis on each and every individual component associated with PV system. The main components on which he made analysis are converters and its types, inverters and its types and also on batteries. He also form a strong basis for each and every part associated with the PV system.

[9] S.P.Sukhatme in his book he had suggested many hybrid methods to reduce cost of the renewable energy system. In addition he also suggested methods to reduce the cost as well space occupied by such renewable energy system. Thermal analysis of solar flat plate collector is discussed in detail in his book. Losses associated with solar flat plate collectors where also discussed with the methods of overcoming such losses. He also discussed about the right selection of materials for each and every part of the solar flat plate collector. His step by step sequence of obtaining the performance of FPC is more useful in this work for solving the thermal part. In addition he also forms strong basis for electro-thermal analogy and most useful concept in bridging the gap between electrical with thermal field. He laid a strong foundation for the introduction of simultaneous generation electrical and thermal power by making use of renewable energy sources available in abundant.

[4] José R. Espinoza made an detailed analysis in the field of inverters. He formulated mathematical model for various inverters. In addition he also developed simulation model for inverters. He suggested many application oriented inverters. He also discussed about right selection of inverters along with its simulation models.

All those above clues lead the idea of drafting and designing this new PV/T water collector system which is economically viable. Such newly designed PV/T collector with transparent glass allows much more sunlight to fall on the pipe carrying cold water as a mean of which rate of heat transfer from the tube to that of transporting fluid has been improved. Thus results in the overall performance improvement in case PV/T hybrid water collectors.

III.EXPERIMENTAL SETUP

In this work conversion of electrical power from source to receiver remains same as that of the normal PV cell power conversion. As principal source sun delivers rays it is absorbed by the PV cell. Then the cell converts absorbed heat in DC power. Then Inverters are used to convert DC to AC. There are two types of inverters: (a) stand-alone or (b) grid-connected. Both types have several similarities but are different in terms of control functions.

The basic working principle of photovoltaic/thermal water collectors has been explained simply with a help of fig (1) shown below.

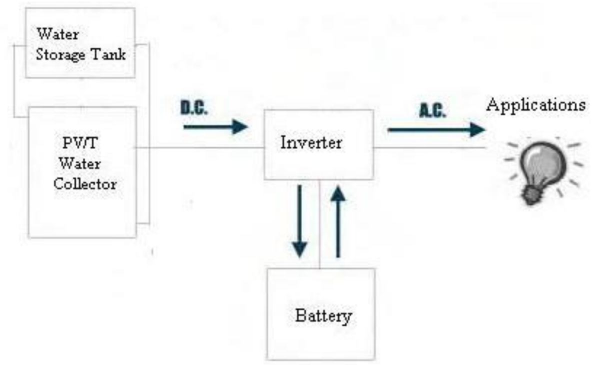

Fig (1) Working principle of hybrid PV/T water collector.

A stand-alone inverter is used in off-grid applications with battery storage. From the battery power stored has been discharged. The main drawback of existing PV/T system was explained with the help of line diagram (b) given below. It consist of four layers mainly top layer is a glass cover which reduces top losses. Sunlight passes through the glass cover and falls on the PV cell mounted on the nontransparent sheet by radiation heat transfer. The from layer two heat is transmitted to the heat pipe through conduction mode of heat transfer but it was less effective in case of non sunny days as well as during winter seasons. The reason for that is intensity of radiation during winter season are lesser than the summer days. As a mean of rectifying this problem PV cells are mounted on the top face of upper glass cover (Layer 1) itself.

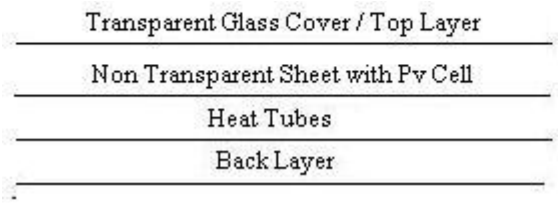

Fig (2) Cross section of existing hybrid PV/T water collector.

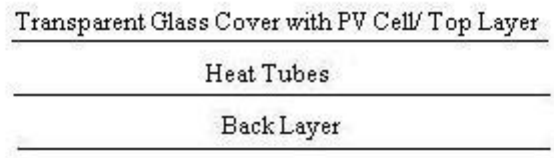

Fig (3) Cross section of new hybrid PV/T water collector.

As seen from the above fig (2) and (3) new collector introduced via this work was differentiated from the existing collector with the reduction of second layer. In modification of that second layer which produces loss in thermal efficiency was combined with the first layer (transparent cover).Sun light falling on the top layer which is transparent allows rays falling on it to the next layer without retardation. With help of such modification energy falling on the glass cover allows entire rays falling on it to the next layer (thermal power generation layer).As a mean of which loss was being reduced. Since we know that the transparent glass cover has the transmissivity value of 1 as per radiation heat transfer.

The working principles of fluid flow through heat tubes was shown in Fig (4).

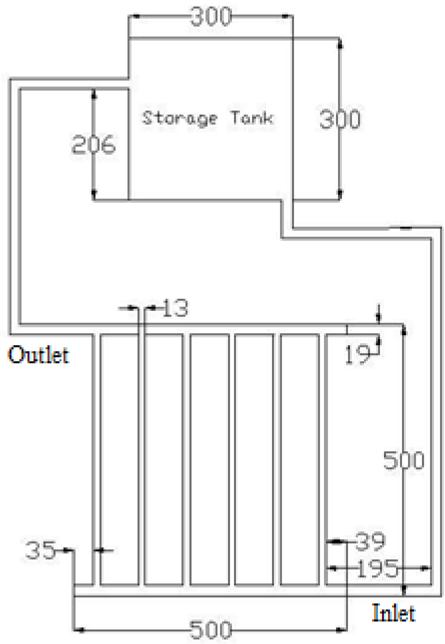

Fig (4) Thermal Components with tank and collector.

Such experimental setup has been tested for its improved thermal performance. New set PV/T collector gets an improved performance in terms of both electrical and thermal output aspects.

IV.FORMULAS

A.ELECTRICAL PART:

The performance of electrical system will be determined using same procedure to that of single system analysis. As a mean to explain formula used to calculate electrical performance consider a common mathematical model.

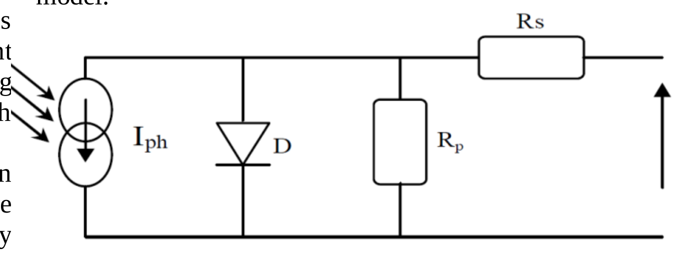

Fig (5) Equivalent circuit for PV cell.

The current source Iph represents the cell photocurrent. Rp and Rs are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of Rp is very large and that of Rs is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in a parallel-series configuration to form PV

arrays.

The photovoltaic panel can be modeled mathematically as given in equations (1) – (4)

Module photo current is given as

$$Iph=[Iscr+Ki(T-298)]*\lambda/1000 \quad (1)$$

Module Reverse Saturation current

$$Irs=Iscr/[exp(q.Voc/Ns.k.A.T)] \quad (2)$$

The Module saturation current I_0 varies with the cell temperature which is given by

$$I_0=Irs*[T/Tr]3exp[q*Ego\{(1/Tr)-(1/T)\}] \quad (3)$$

The Current of the PV module is given by

$$Ipv=Np*IphNp*I0[exp\{(q*Vpv+Ipv*Rs)/NsAkT\}] \quad (4)$$

where, Vpv=Voc,Np=1,Ns=36.

B.THERMAL PART:

The performance of thermal system will be determined using same procedure to that of single system analysis. As a mean to explain formula used to calculate thermal performance consider a common mathematical model.From [9] Sukhatme, Formula used to calculate efficiency of thermal flat plate collector has been defined as ration of useful heat gain to radiation incident on the collector.

$$\eta = Qu / Ac.It \quad (5)$$

Where as

$$Qu = F_R*Ap*[S-U_l(T_{fi}-T_{fa})] \quad (6)$$

V.THEORITICAL SIMULATION

With reference to Krismadinata [5] the simulations has been made for PV. The simulations were classified in to two types i) Full system simulation (Fig: 8) (Appendix: 1) ii) Subsystem simulation. They are discussed in detail as follows.

A. Subsystem: 1

This model converts the module operating temperature given in degrees Celsius to Kelvin.

B. Subsystem: 2

This model takes following inputs.
Insolation/ Irradiation – (G / 1000) 1 kW/ m2= 1.
Module operating temperature TaK = 30 to 70°C. Module reference temperature TrK = 25°C. Short circuit current (ISC) at reference temp. = 2.9A.

C. Subsystem: 3

This model takes short circuit current Isc at reference temp. = 2.90A and Module reference temperature Trk = 25°C as input.[1].Using equation 2, the reverse saturation current of the diode is calculated in subsystem 3.

D. Subsystem: 4

This model takes reverse saturation current Irs, Module reference temperature Trk= 25°C and Module operating temperature Tak as input and calculates module saturation current.

E. Subsystem: 5

This model takes operating temperature in Kelvin Tak and calculates the product NsAkT, the denominator of the exponential function in equation (4).

F. Subsystem: 6

This model executes the function given by the equation (4). The following function equation is used. IPV = u (3)-u (4)*(exp ((u (2)*(u (1) +u (6)))/ (u(5)))-1)

S.No	Parameters	Value
1.	Rated Power	3.8Watt
2.	Voltage at Maximum power (Vmp)	10.5 V
3.	Current at Maximum power (Imp)	0.36 A
4.	Open Circuit Voltage (Voc)	21.6 V
5.	Short Circuit Current (Iscr)	2.9 A
6.	Total number of cells in series (Ns)	16
7.	Total number of cells in parallel (Np)	1
8.	Input Voltage	10-12 V
9.	Output Voltage	150-200(DC)
10.	Switching Frequency(f)	10 KHz
11.	Duty Cycle (D)	0.4 < D < 0.8
12.	Inductance (L1)	20mH
13.	Capacitance	110 µF
14.	Switch Type	IGBT

Table 1: Parameters of PV system simulation.

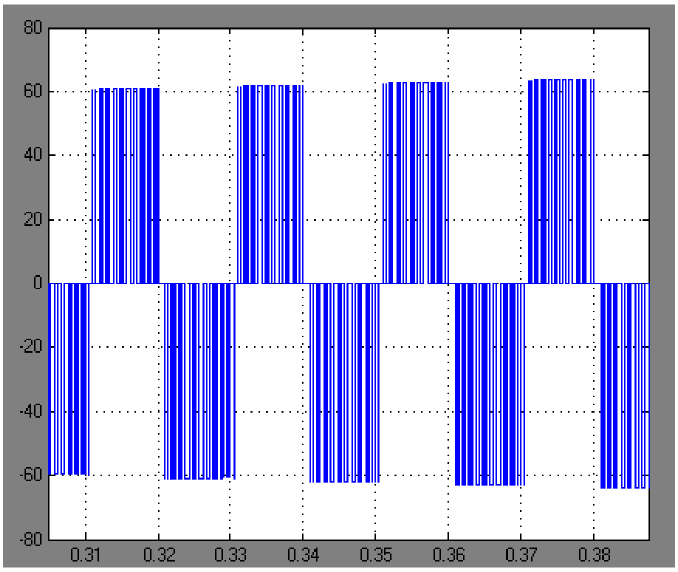

Fig (6): AC Output of Inverter.

The step-by-step procedure for modeling the PV module is presented. This mathematical modeling procedure is for determining the voltage, current and power from PV panel (electrical output). The output from PV is dc. Since ac power is used for domestic purpose we are using inverter to get ac output. The main drawback of PV is, it produce very low voltage it can't be not much enough for home appliances. So Boost converter is used to boost the voltage from 10v-70v. The output from boost converter is dc. Since ac power is used for domestic purpose, inverter is used for conversion of dc-ac. From boost converter it is given to the inverter for ac output. The graph shows the ac output from inverter.

VI RESULTS AND DISCUSSIONS

It is cleared that the concentration in this work was shown to reduce drop in thermal efficiency of existing PV/T. Such problem was rectified and been proved with the new PV/T hybrid water collector.

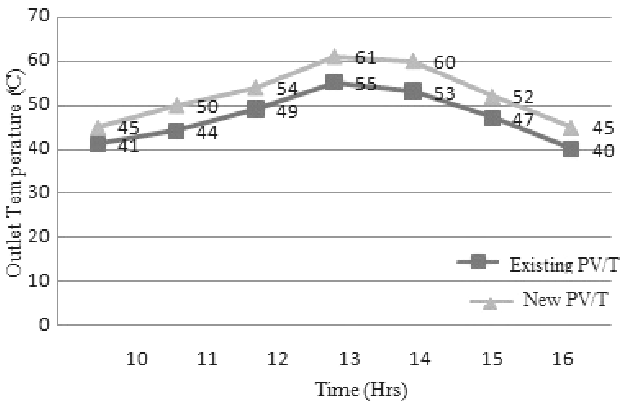

Fig (7): Variation of outlet temperature with time.

Time	Solar Intensity	Case 1 Conventional PV/T		Case 2 New PV/T	
IST (Hrs)	I (W/m^2)	T_o (ºC)	η (%)	T_o (ºC)	η (%)
10.00	722.6	41	40.60	45	42.71
11.00	859.4	44	39.25	50	41.07
12.00	937.5	49	37.54	54	40.37
13.00	917.9	55	36.10	61	39.00
14.00	820.3	53	33.29	60	37.98
15.00	761.7	47	32.82	52	36.25
16.00	605.5	40	31.00	45	33.85

Table 2: Experimental & theoretical data's of FPC.

With reference to the above new experimental setup (PV cells mounted on FPC's glass cover itself), it is cleared that sunrays will pass through the space between solar cells connected in series. With respect to time It is cleared that existing system with non transparent solar cell mounted sheet produces less outlet temperature as compared to the new PV/T with transparent glass topped solar cell.

The outlet temperatures obtained by the new PV/T collector was expected to be 4ºC-5ºC greater than the existing PV/T water collectors. The peak temperature obtained by the new designed transparent PV/T is 61 ºC where as existing non transparent PV/T produces 55 ºC .The reason of suggesting current work was identical with this variations. The overall thermal efficiency of the new PV/T system also expected to be 3%-4% higher than the conventional PV/T water collectors. The approach of experimentation procedure for calculation of electrical as well as thermal efficiency remains same for both the cases but the effect of increase in heat transfer through the transparent glass cover differentiates and clears the advantages of new PV/T Collectors.

VII FUTURE WORK

In view on electrical part cell efficiency goes on decreasing as the cell got heated. The measures necessary to maintain optimum temperature of cell to maintain its performance with increase in time are to be considering in future extension. In case of thermal part experiments with different mass flow rates of the heat transport fluid and also to conduct simulation of for thermal part using ANSYS 15.0 software. In addition various readings are also to be optimized using optimization techniques like ANN.

APPENDIX: 1

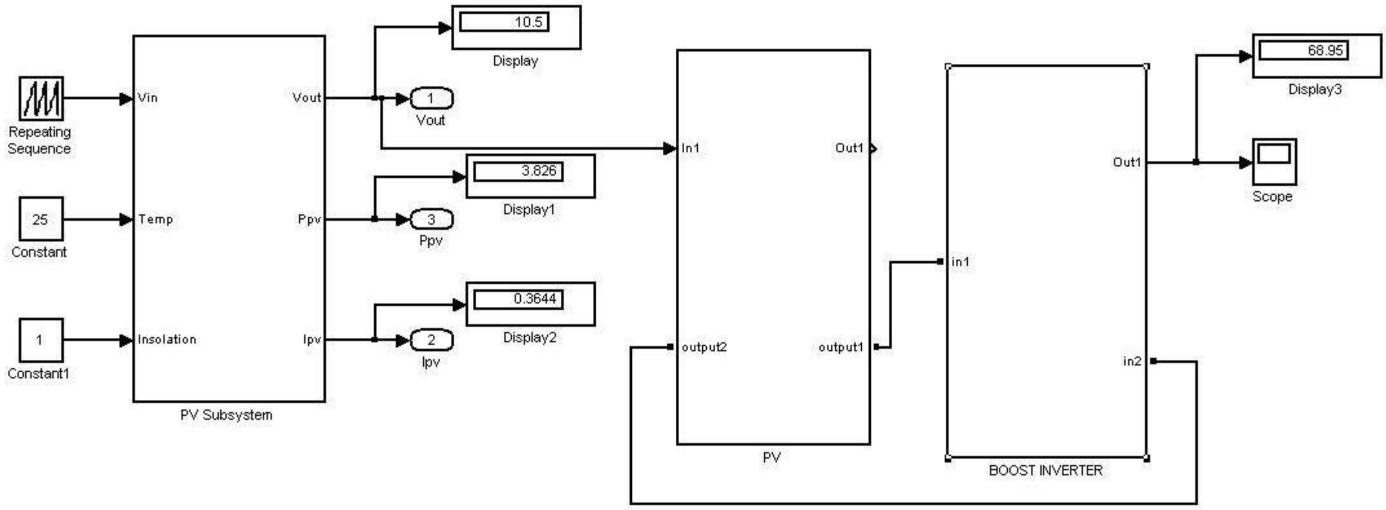

Fig (8): Matlab model of Full PV System.

NOMENCLATURE

Vpv - Output voltage of a PV module (V),
Ipv - Output current of a PV module (A),
Tr - Reference temperature = 298 K,
T -Module operating temperature in Kelvin,
Iph - Light generated current in a PV module (A),
Io - PV module saturation current (A),
A -B - An ideality factor = 1.6,
k - Boltzman constant = 1.3805 × 10-23 J/K,
q - Electron charge = 1.6 × 10-19 C,
Rs - The series resistance of a PV module,
Iscr - PV module short-circuit current at 25ºC,
λ - PV module illumination (W/m2) =1000W/m^2,
Ego - Band gap for silicon = 1.1 eV,
Ns - Number of cells connected in series,
Np - Number of cells connected in parallel.
F_R-Heat Removal Factor,
Ti-Fluid inlet temperature.
Tfo-Fluid outlet temperature (ºC),
Tak-Fluid ambient temperature (ºC),
It-Intensity of radiation measured using pyranometer (W/m^2).
Qu- Utilised heat(W/m^2),
η – Efficiency in (%).

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